by

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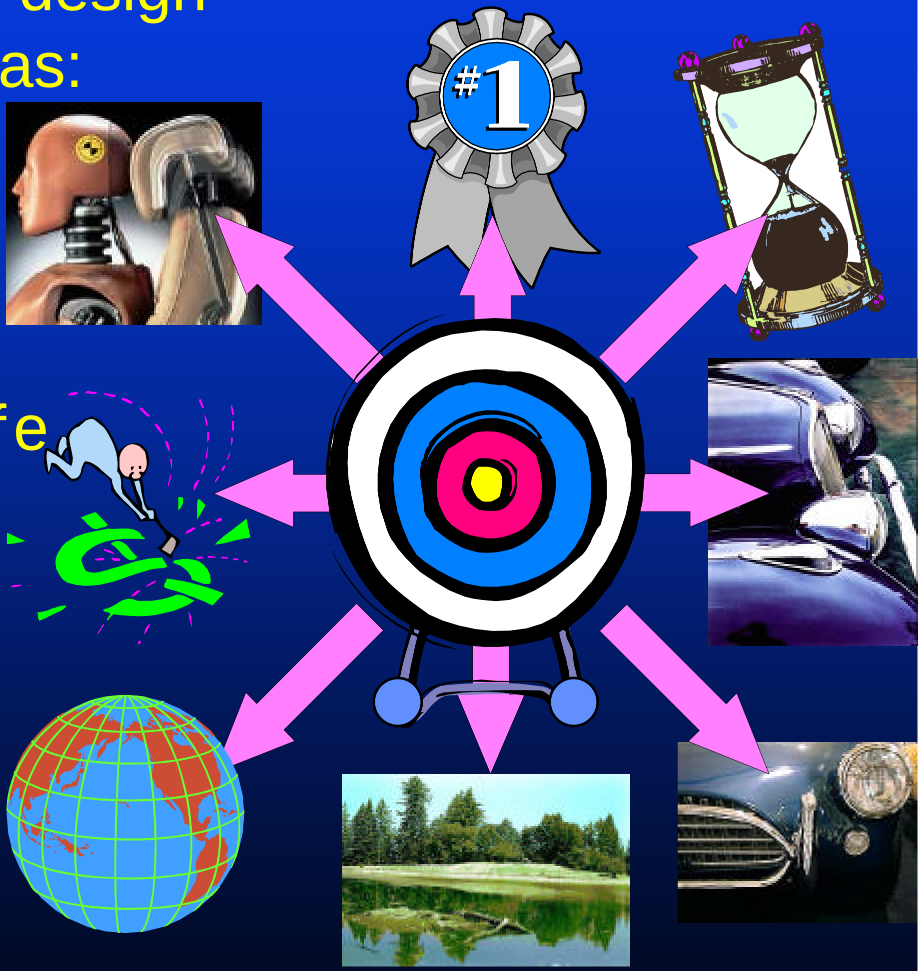
Contradicting Design Requirements

The need for innovative tools is apparent now more than ever as more complex design requirements are surfacing such as:

- Cost
- Performance & safety
- Quality
- Time to market & short life cycle
- Environmental impacts
- Aesthetics (wow, lust for the product, I got to have it ...)
- Major Changes in Industry's Business Model



- Cycle development time from concept to production is being compressed significantly
  - 1992: 60 months
  - 1996: 48 months
  - 2000: 18 months
- Vehicle designs are tailored to focused markets
- Vehicles are being manufactured more on a global scale
- Vehicles designed increasingly through multiple engineering sites around the world
- Need for enabling companies throughout the supply chain and extended enterprise to share information through a web-centric visualization approach

Design Process Status:

- Great **Advances in the Design Process**
  - Moving from paper drawing to electronic drawing
  - Moving from electronic drawing to 3D wire frame
  - Moving from 3D wire frame to solid modeling
  - Moving to Parametric feature based solid modeling (commodity: Granite, Para-solids, Acis, etc)
  - PDM/ERP/MRP/PLM ???
  - Still tradition and experience govern the design choices

- What is next
  - Integrated Product Development Process (AEE)
  - Knowledge capture and reuse (KBE)
    - Documentation of rationale for the design
    - Best practice automation (Self designed parts)
  - Collaborative design

Engineering Design and Simulation Tools

- The simulation tools such as FEA, CFD, CAM, although easier to use and better integrated with CAD, become more powerful and more complex.
- Typically by the time they provide feedback to a design that design has evolved over several iterations due to packaging, cost, availability, manufacturing, etc.
- Behavioral modeling provides ***a return to simplicity*** by imposing fundamental engineering rules at the CAD level.
- Behavioral modeling is a new paradigm shift in the design process empowering engineers to create optimum, innovative, requirement driven designs on their first try.

Quality - Robust Design

- **Definition** of **Robust Design**:
  Deliver customer expectations at profitable cost regardless of:
  - customer usage
  - variation in manufacturing
  - variation in supplier
  - variation in distribution, delivery & installation
  - degradation over product life

- **Goals** of Robust Design (shift and squeeze)
  - Shift performance mean to the target value
  - Reduce product’s performance variability

Statistical Design Performance Simulation?

" You 've got to be passionate lunatics about the quality issue …"

Jack Welch

"U.S. autos fight poor quality reputation …"

Joe Miller / The Detroit News

" Product quality requires managerial, technological and statistical concepts throughout all the major functions of the organization …"

Josheph M. Juran

Variation (thickness, properties, surface finish, loads, etc.) is … *THE ENEMY*

DOE, Six Sigma, Statistical FEA, Behavioral Modeling … *THE DEFENCE*

Improved Quality reduced Total Cost

Cost of Defect or Failure

- Lost Customers
- Liability (R&D)
- Recalls (production)
- Rework

Examples:

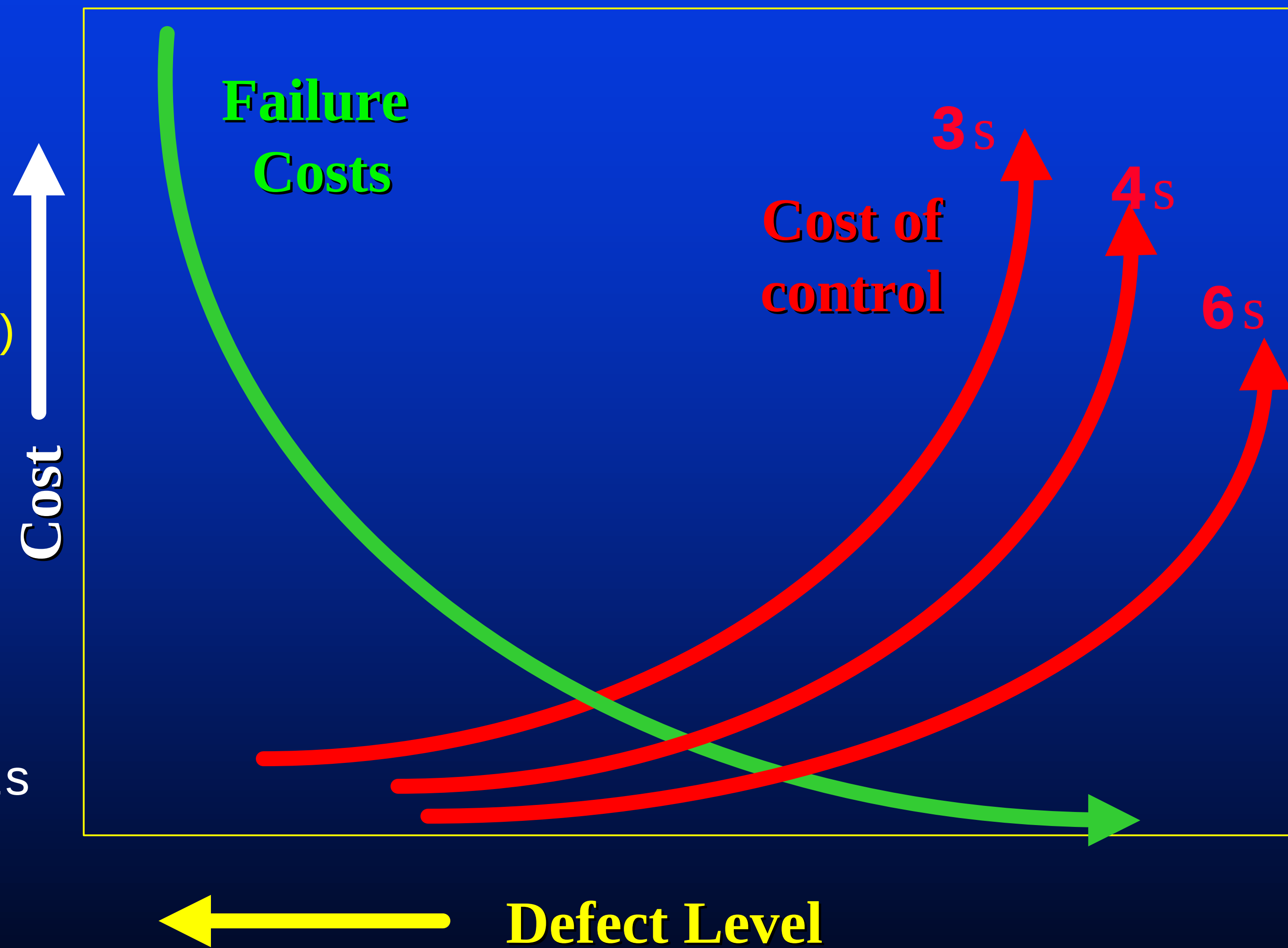
Titanic

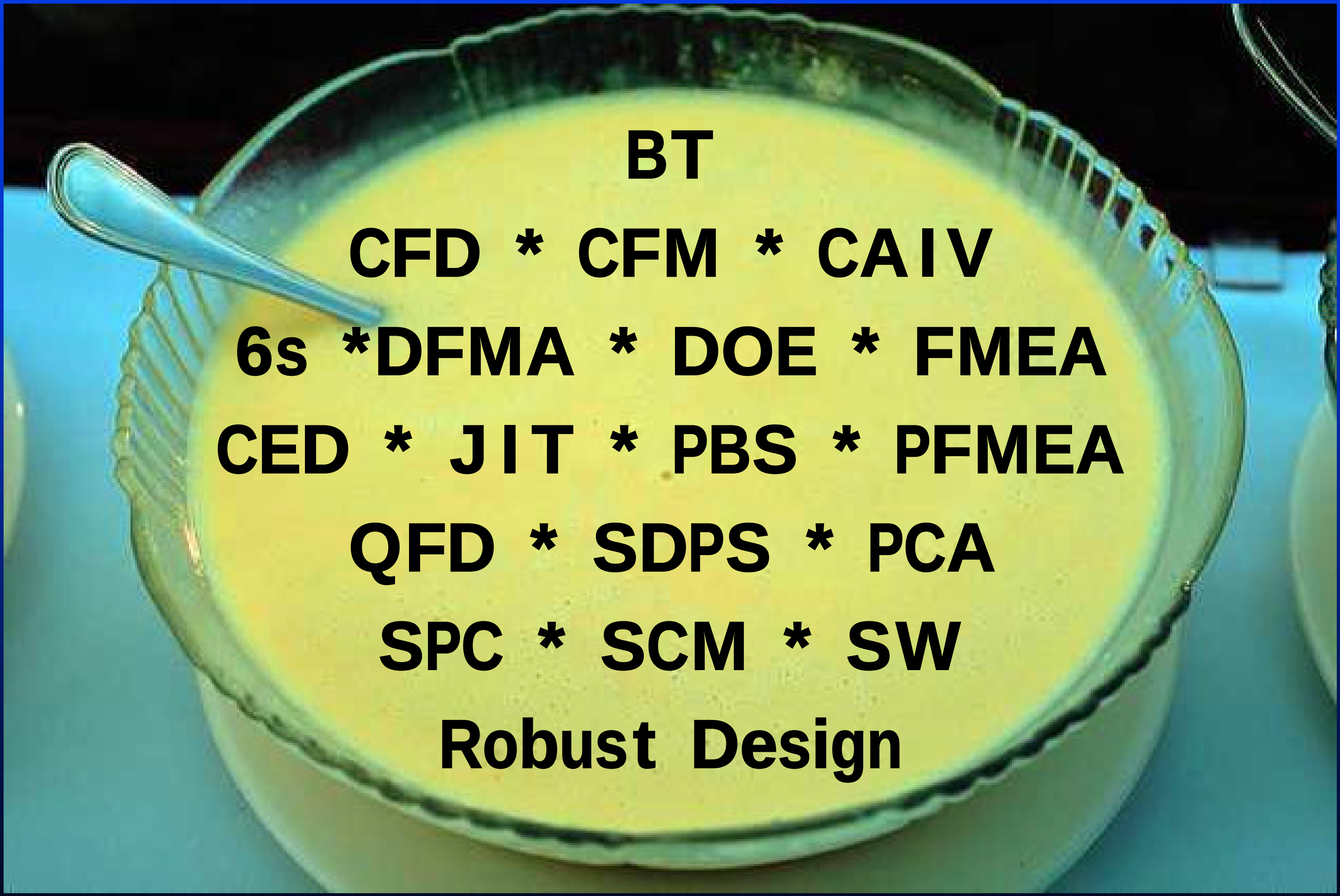
Asbestos

Breast Implants

Bhopal, India

…



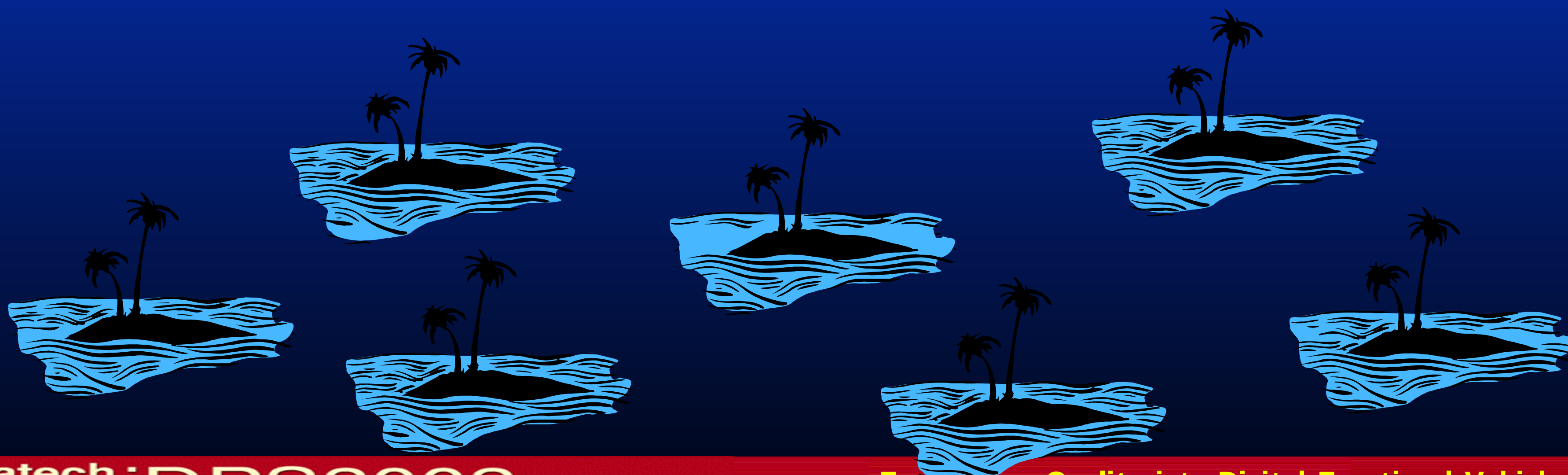

BT
CFD * CFM * CAIV
6s *DFMA * DOE * FMEA
CED * JIT * PBS * PFMEA
QFD * SDPS * PCA
SPC * SCM * SW
Robust Design

Elements of Quality Management Process

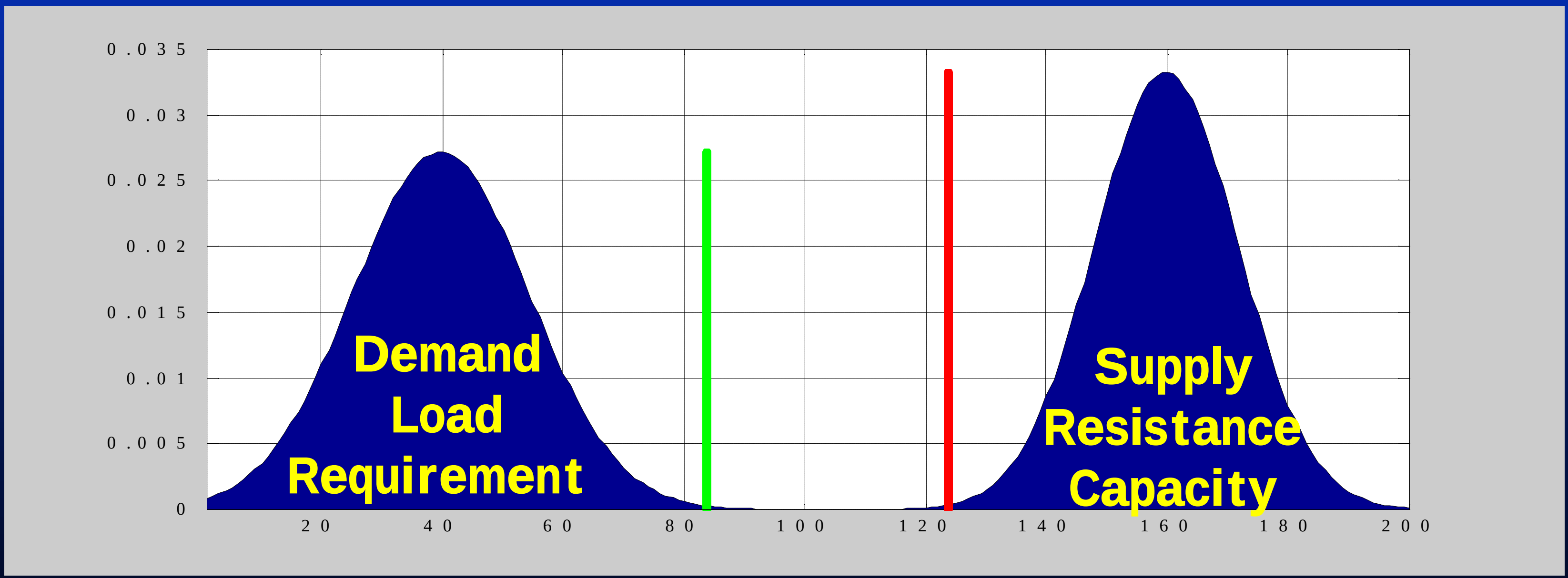
- Agile Improvement Process
- Axiomatic Design
- Benchmarking & Benchtrending
- Catch-ball
- Cellular Manufacturing
- Continuous Flow Development
- Continuous Flow Manufacturing
- Cycle Time Management
- Defect Reduction
- Design for Manufacturing and Assembly
- Design of Experiments
- Failure Modes effects Analysis
- Cause and Effect Diagrams
- Just In Time
- Performance Based Specifications Process Failure Mode Effects Analysis
- Quality Function Deployment
- Robust Design
- Self-Directed Work Teams
- Statistical Design Performance Simulation
- Process Capability Analysis
- Statistical Process Control
- Supply Chain Management
- Synchronous Workshops
- Theory of Constraints
- Thinking Process Reality Trees
- Total Productive Maintenance

Elements of Quality Management Process

- Although all the elements of quality management process are closely connected they remain apart because they have been developed independently from each other
- Integration of these tools is critical to the organization and necessary for successful federation and robust optimization efforts

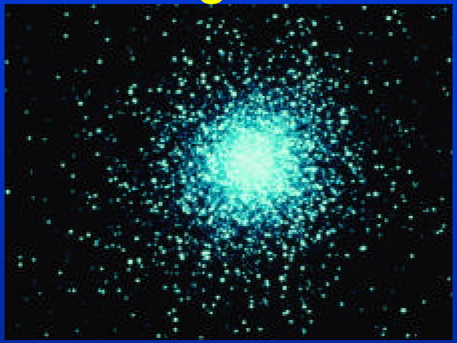


- Accounts for uncertainties through the use of empirical Safety factors:
  - Are derived based on past experience
  - Do not guarantee safety or satisfactory performance
  - Do not provide sufficient information to achieve optimal use of available resources



Noise & Control Parameters

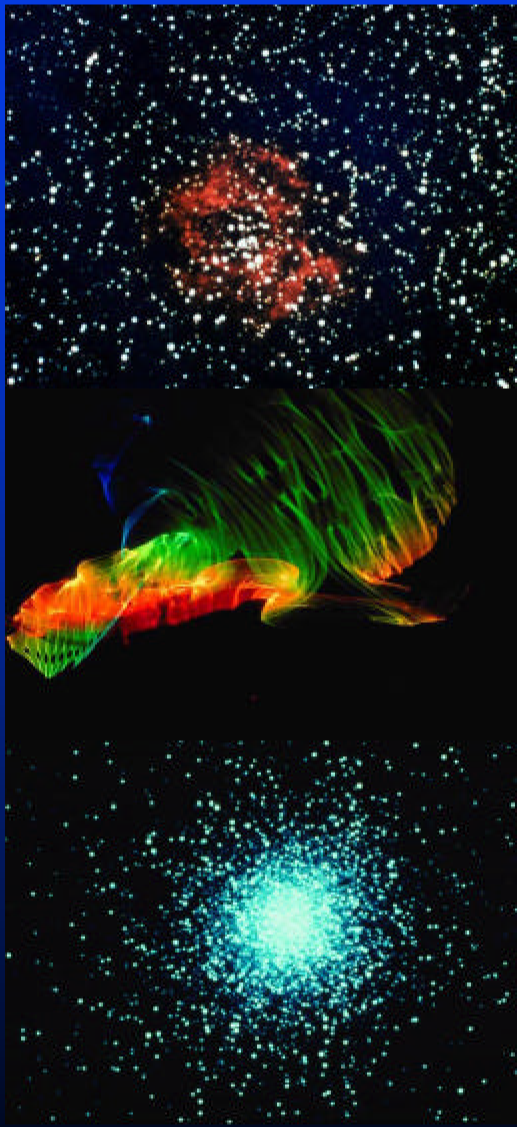
- Noise parameters:
  Factors that are beyond the control of the designer
  - material property variability
  - manufacturing process limitations
  - environment temperature & humidity
  - component degradation with time
  - ...



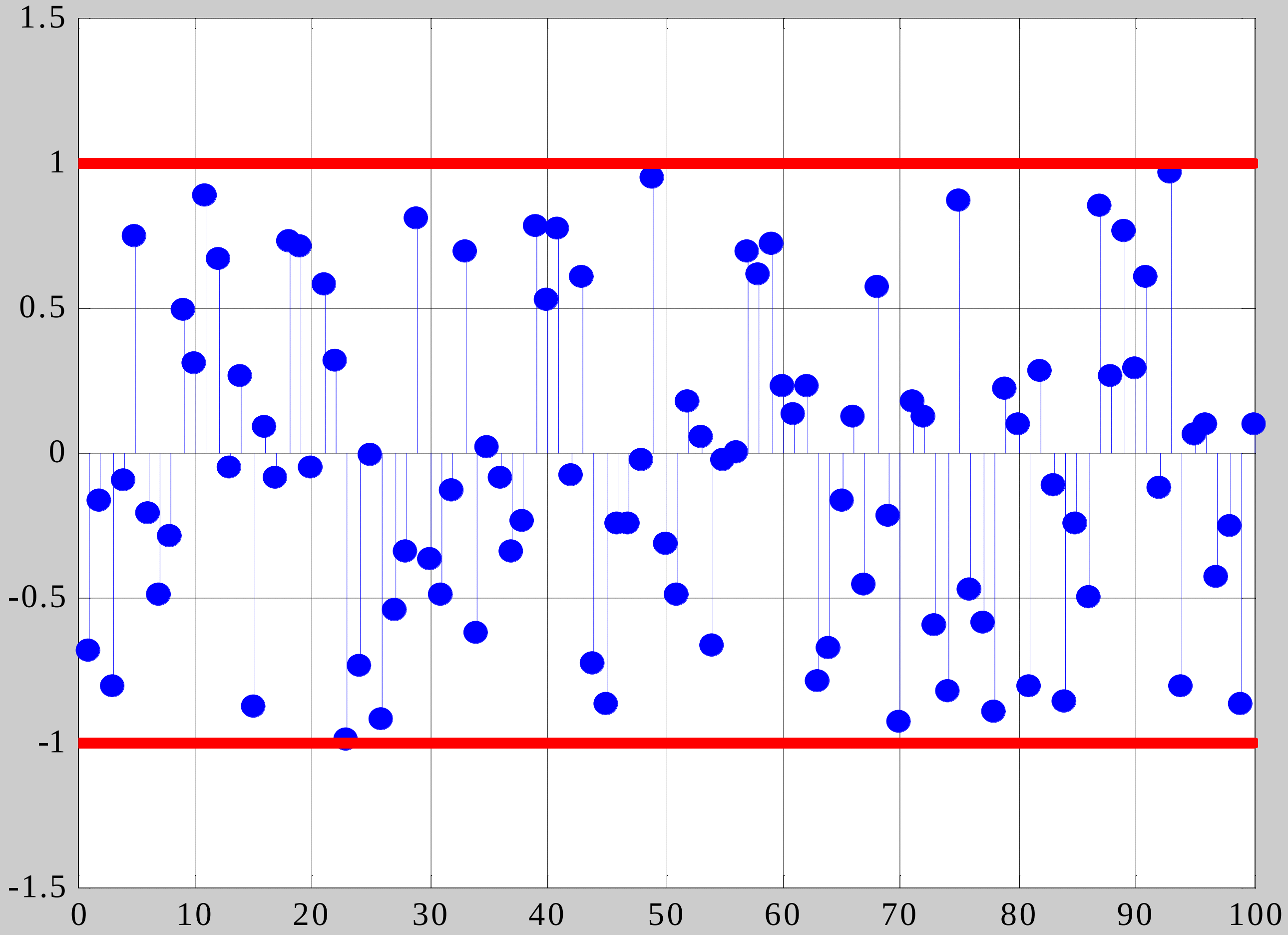
- Control Parameters:
  Factors that the designer can control
  - geometric design variables
  - material selections
  - design configurations
  - manufacturing process settings
  - ...

Tools for Robust Design

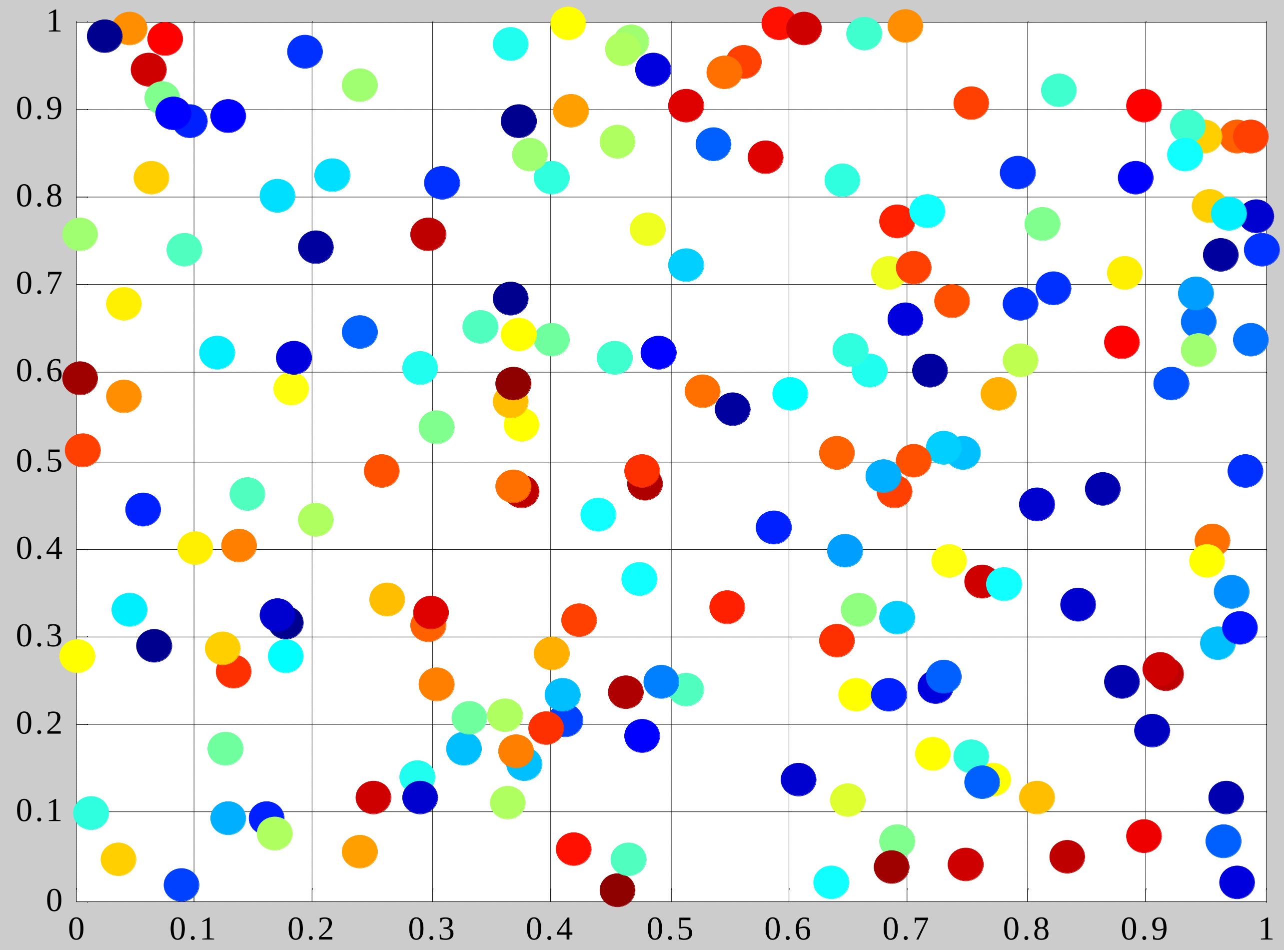
- Design Of Experiments
  - Exploits nonlinearities and interactions between noise & control parameters to reduce product performance variability
  - full factorial, fractional factorial, Monte-Carlo, LHC
- Response Surface Methods
  - Central Composite Design
  - Box-Behnken Design
- 6-sigma design
  - Identifying & qualifying causes of variation
  - Centering performance on specification target
  - Achieving Six Sigma level robustness on the key product performance characteristics with respect to the quantified variation

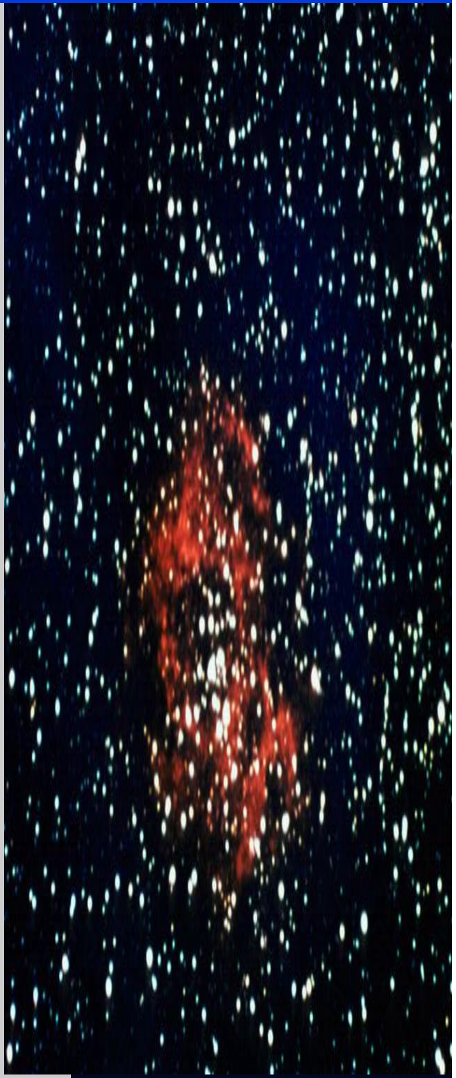


Design Exploration 1 Variable

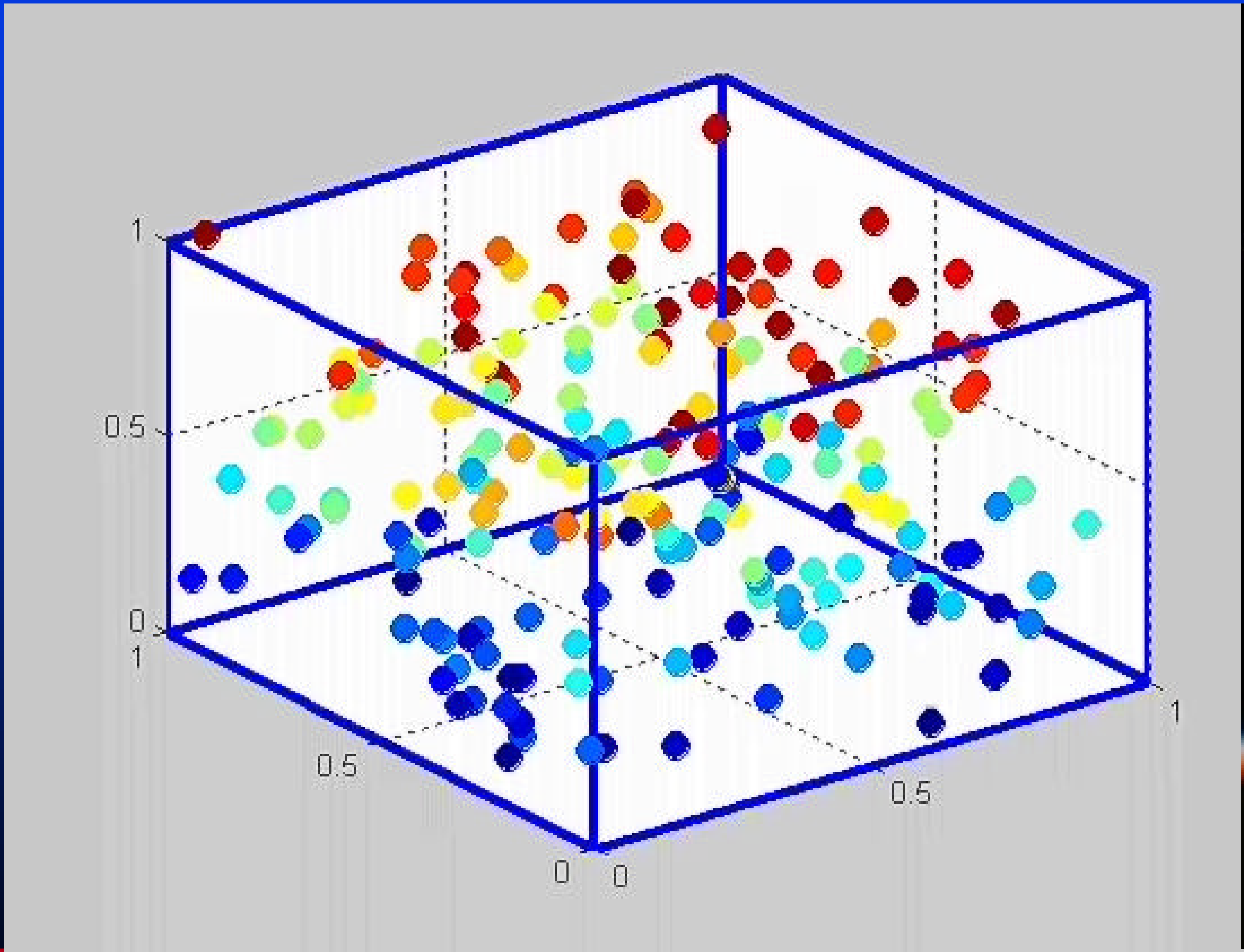


Design Exploration 2 Variables

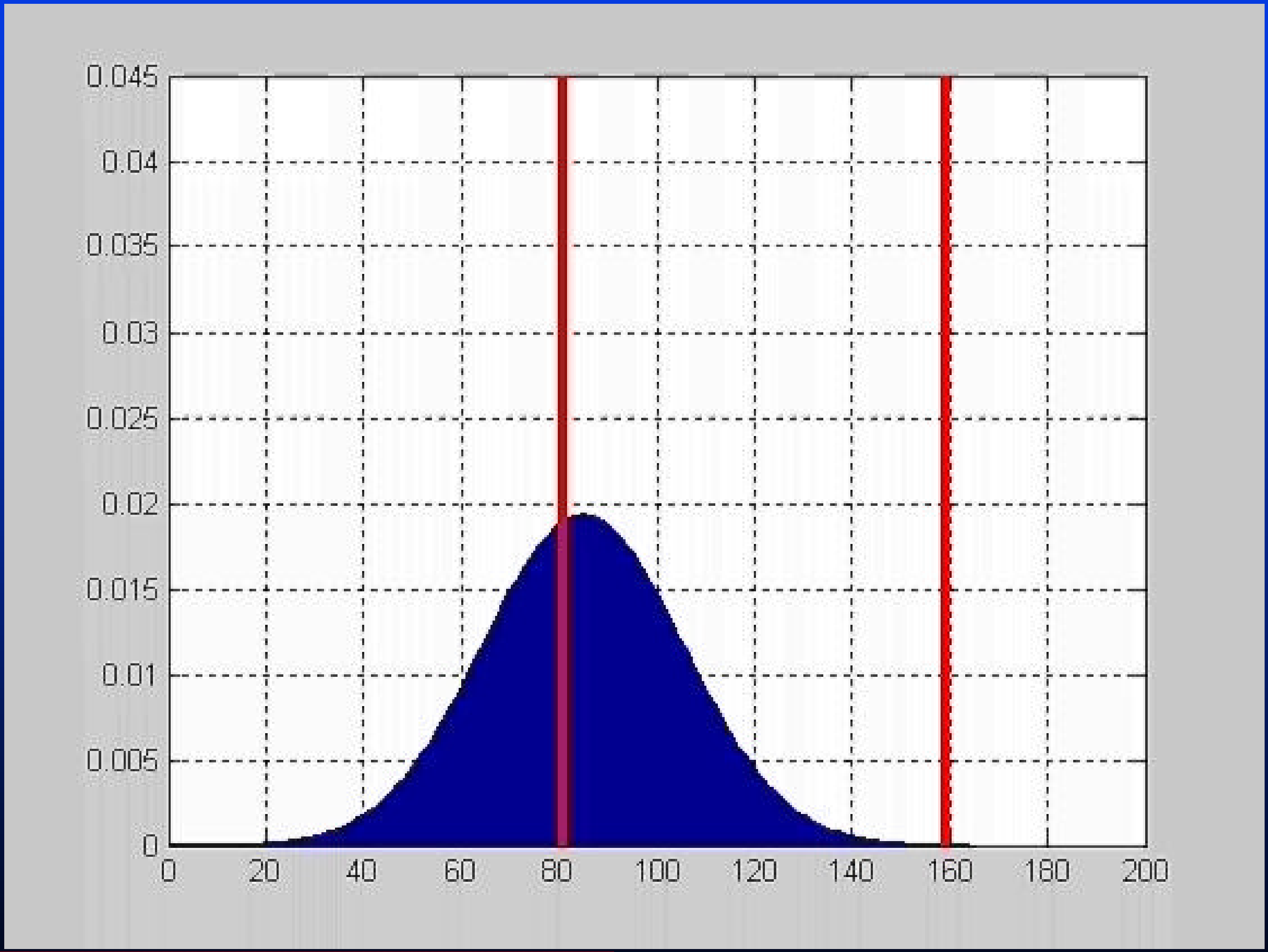




Design Exploration 3 Variables



Shift and Squeeze



CETOL 6σ

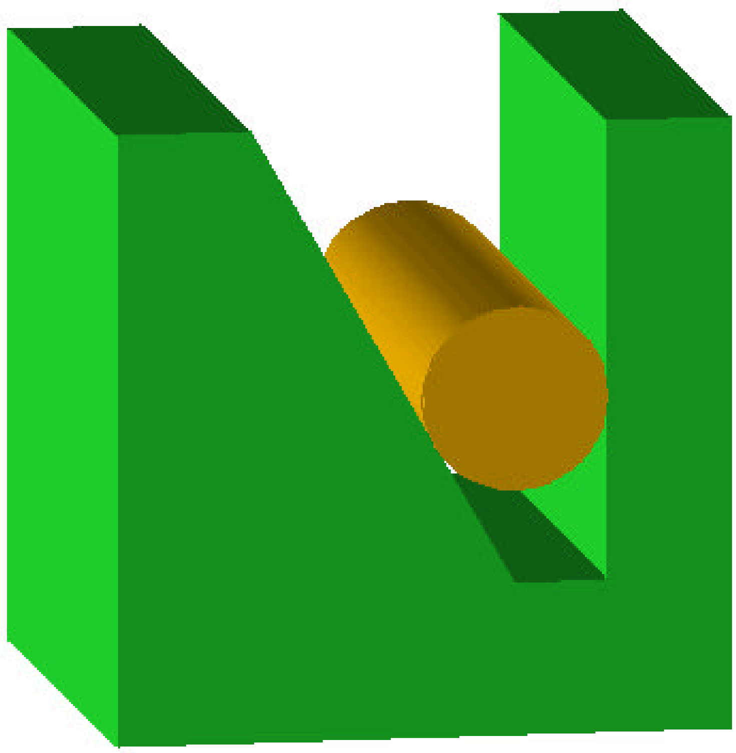
Mechanical Variation Management System

3D Tolerance Analysis / Allocation Software

Sensitivity and Statistical Analysis

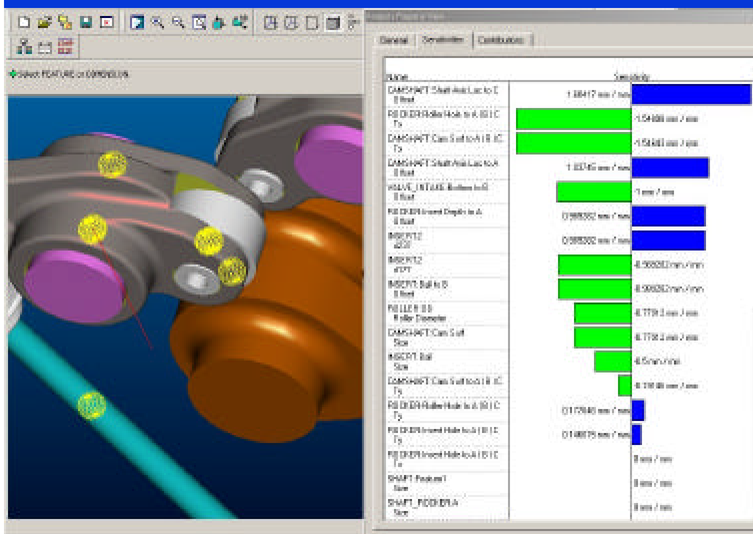
Leverages Mfg Process Capability Data

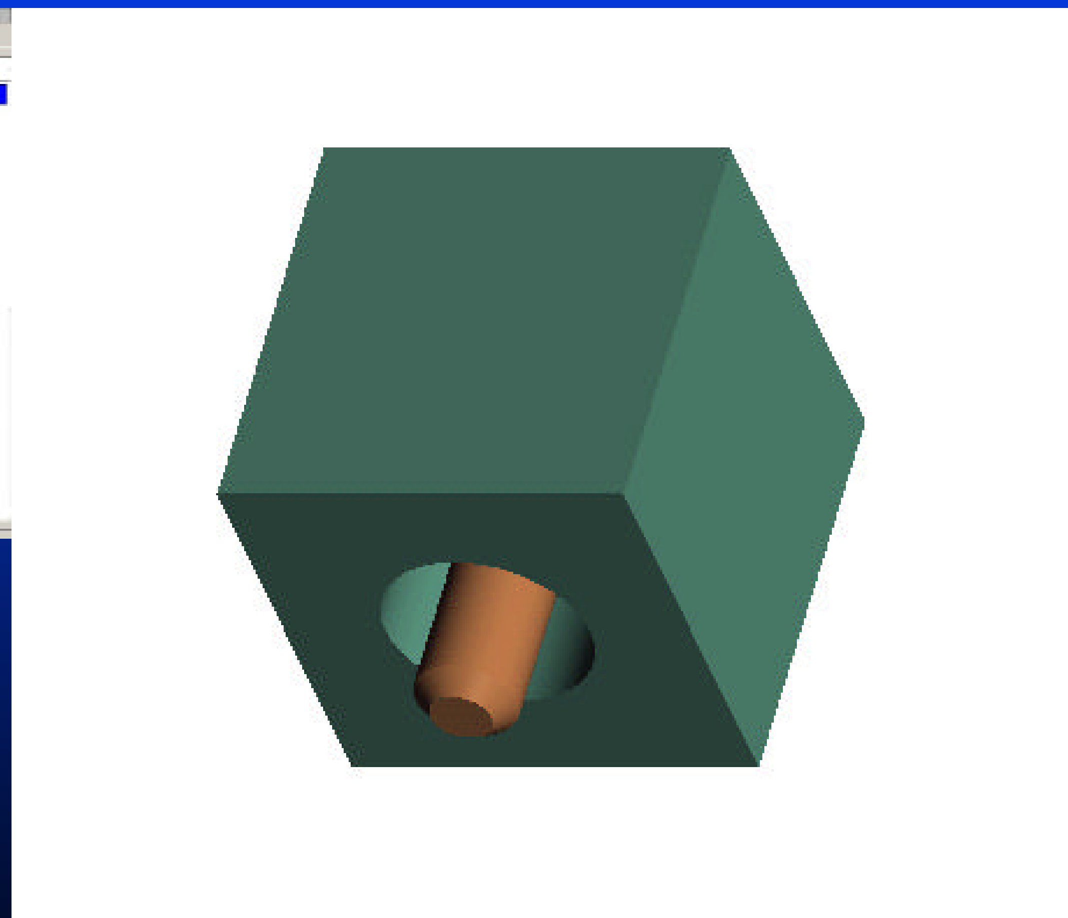
Optimized for DFSS Experts and Pro/E Users



Sources of Assembly Variation:
Multiple Configurations of Assembly

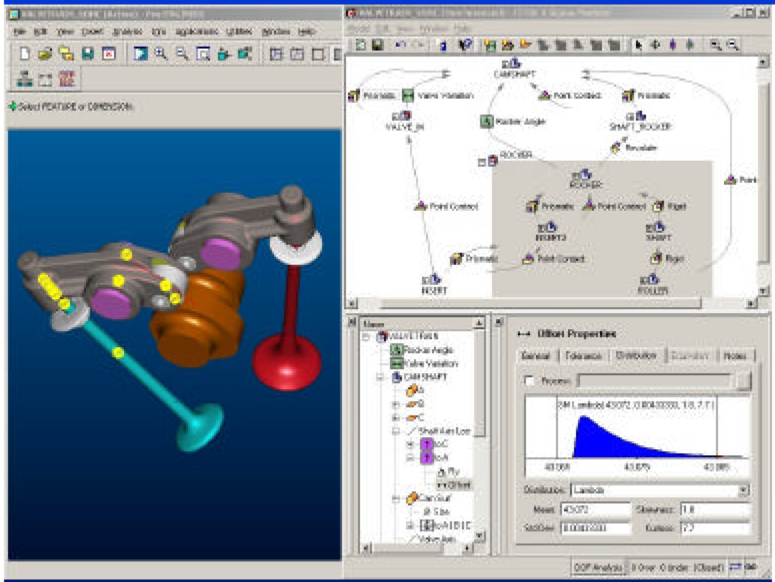
Tools like CE/TOL addresses the issue that one assembly constraint in Pro/E can have many configurations affecting variation

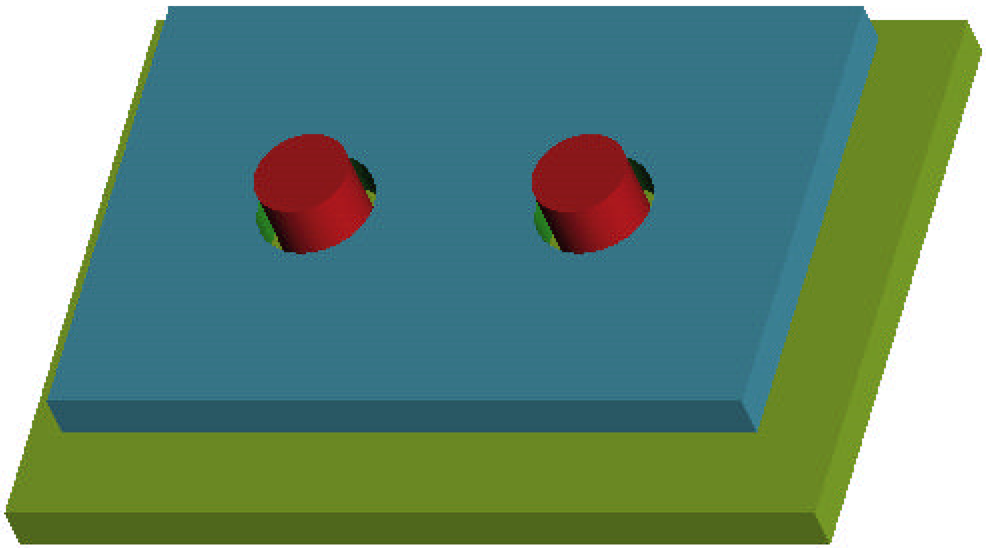




Sources of Assembly Variation: Fastened Interface Variation

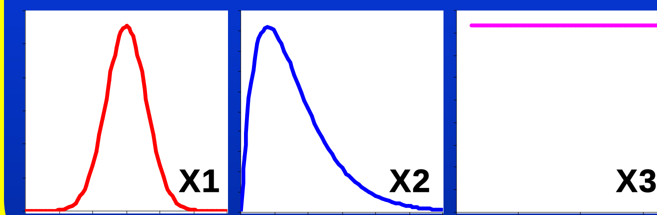
- Higher level assembly constraints require unique representation
- CETOL recognizes full range of configurations





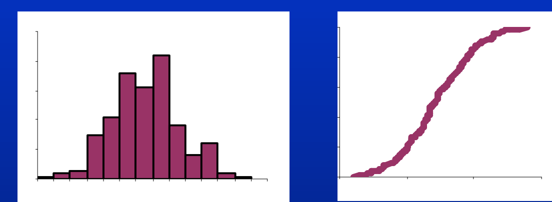
Statistical Design Performance Simulation

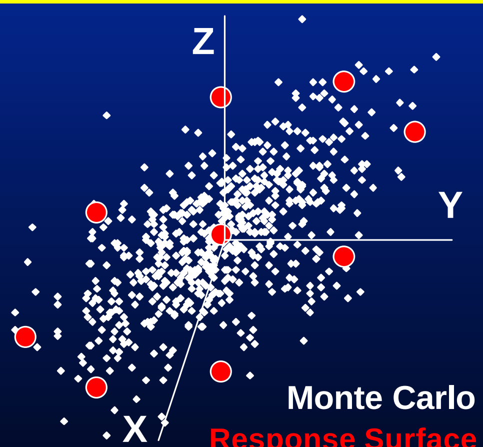
Simulation of input parameters (material, thickness, spot welds, …)



PDS

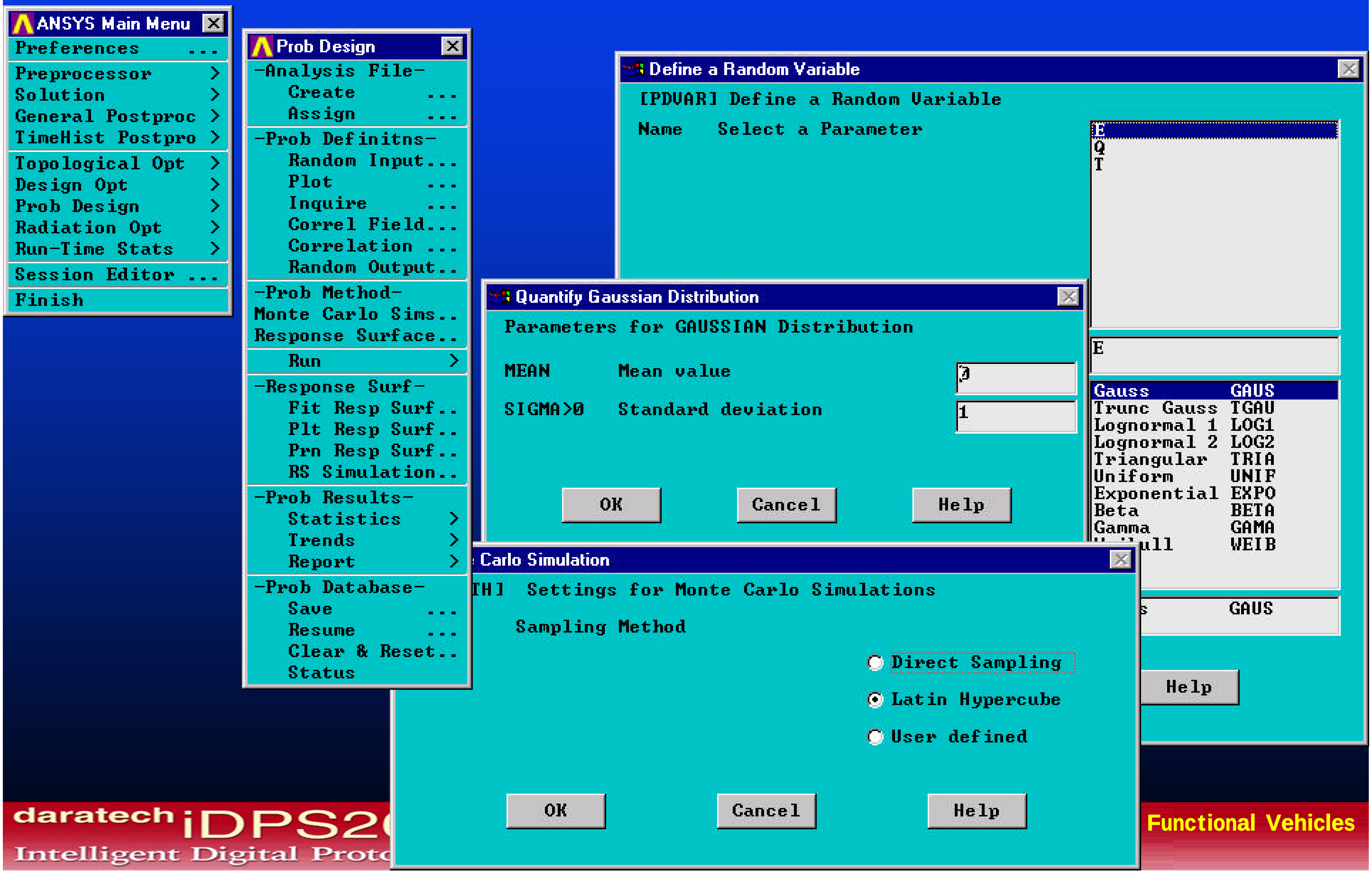
Statistical analysis of output parameters (stress, fatigue life, …)



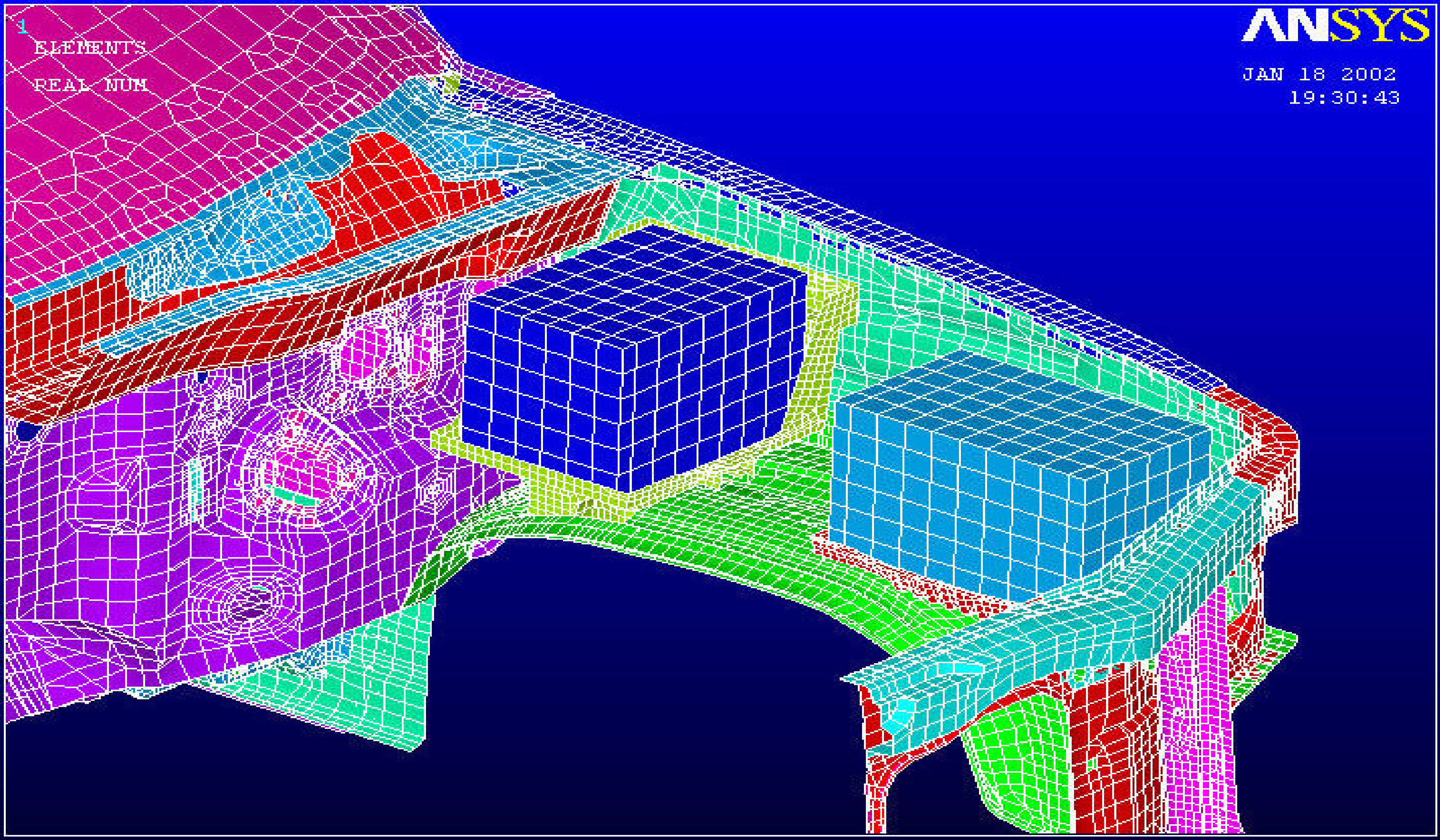


- **Over-design is avoided** (not "as planned", "as is" or the "worst design")
- **Weight Reduction**
- **Six sigma quality**

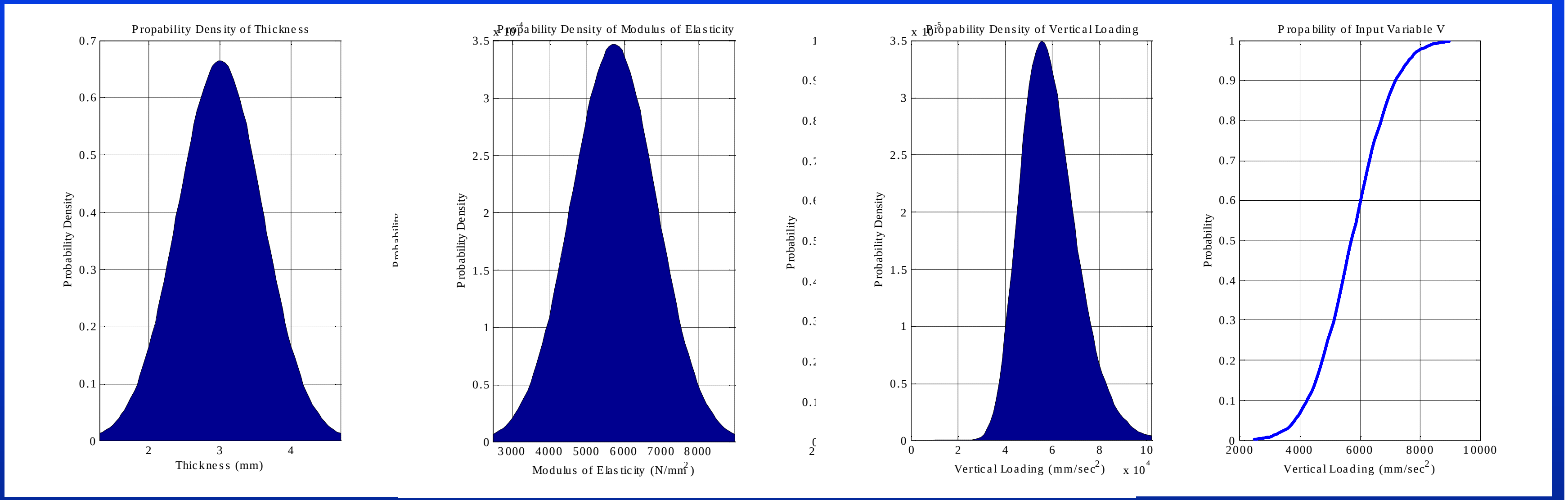
Probabilistic Analysis setup within ANSYS is SIMPLE



Automotive Example



Probability Distributions of input and output variables

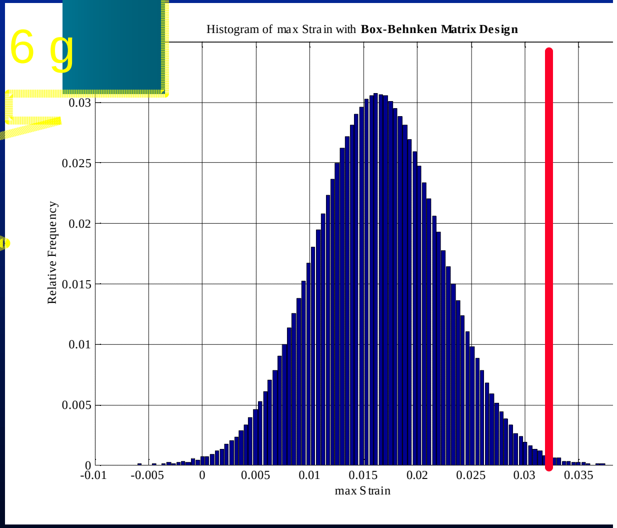


Thickness (3.8-4.2)

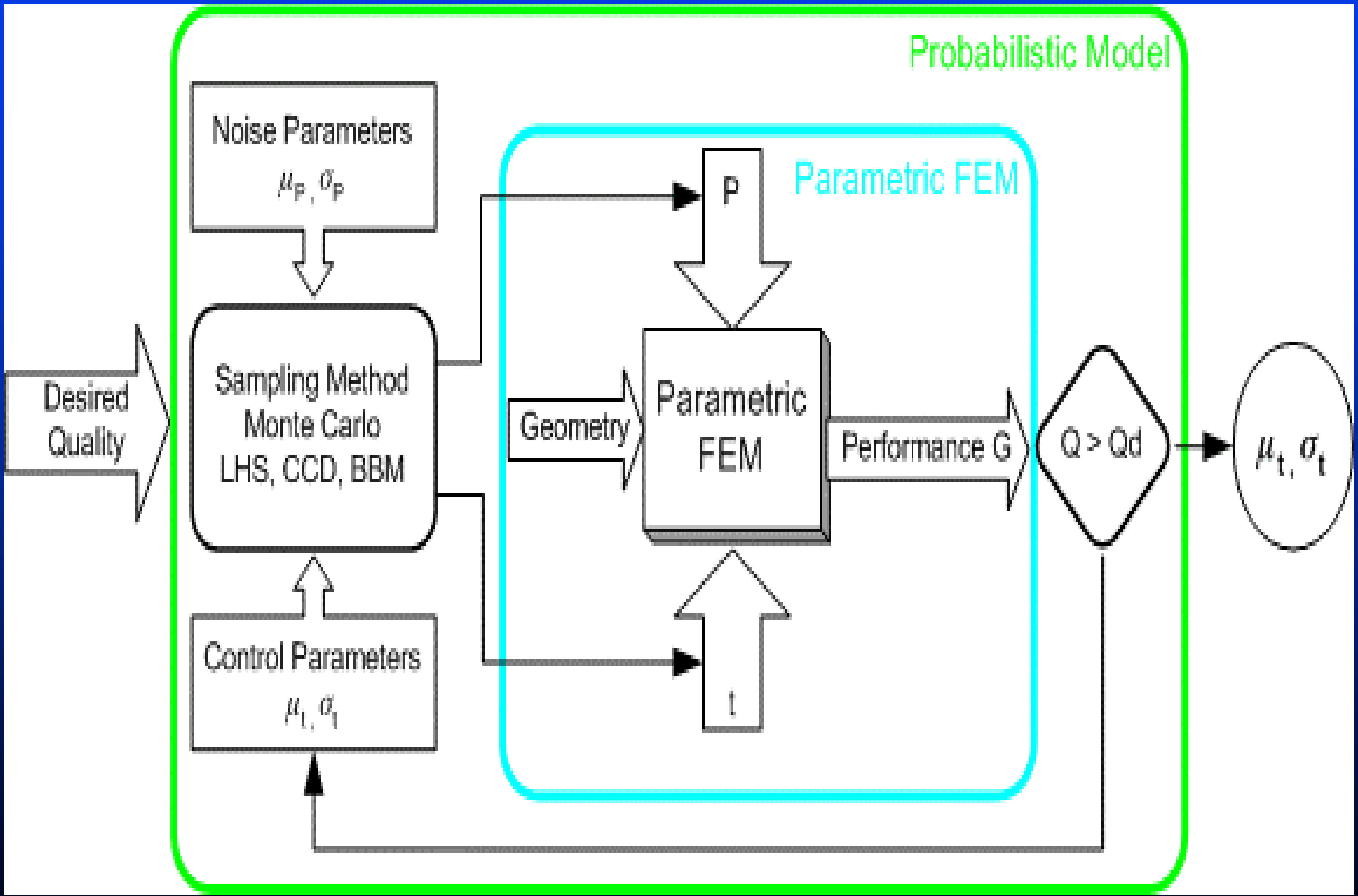
Modulus E

Loading 6 g

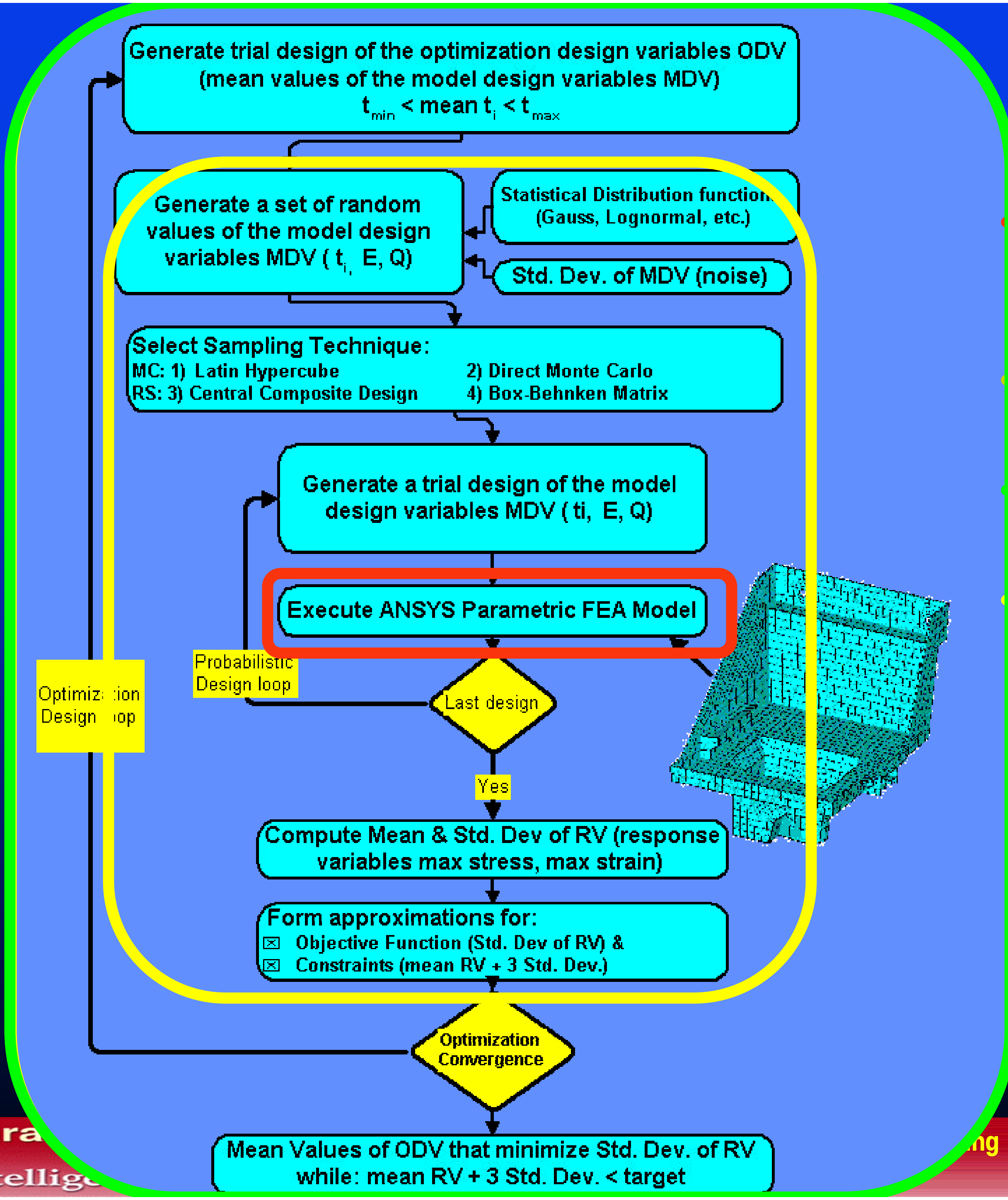
Probabilistic Design Loop



Reliability Based Optimization

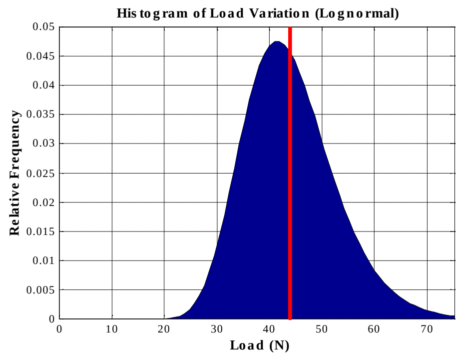


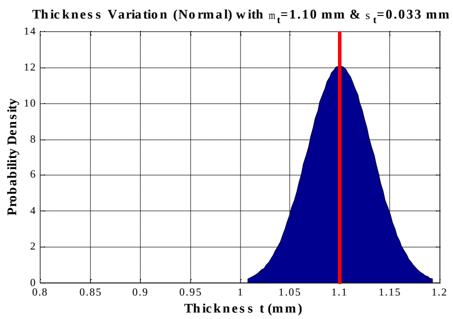
RBO Workflow

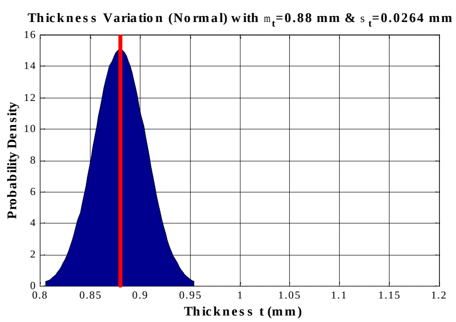


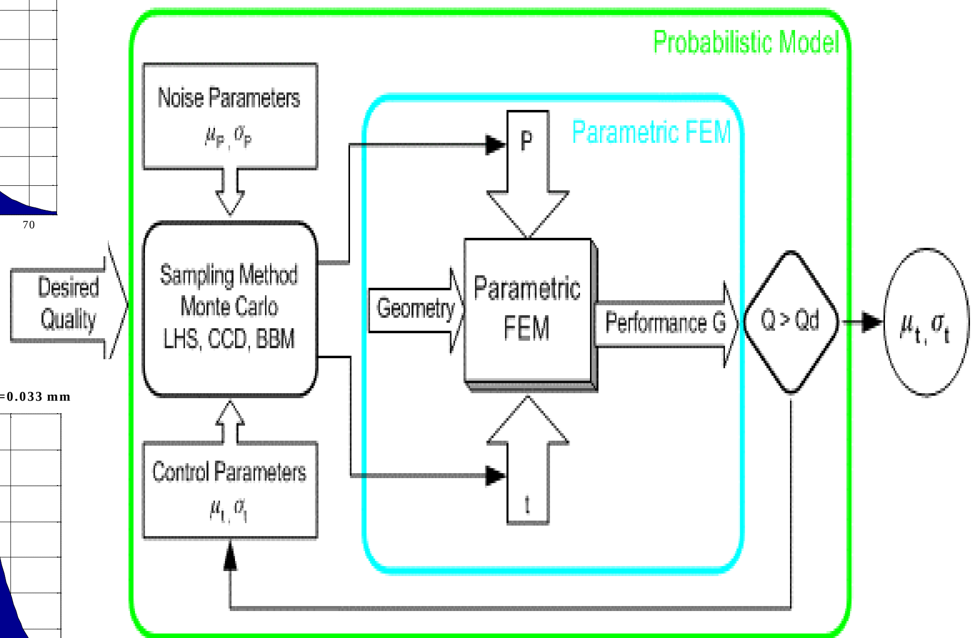
- Automatic, No Manual iteration:
  CAD -> Meshing -> FEA
- Probabilistic Design Loop
- Optimization Loop with reliability constraints
- Deterministic Optimum designs could lead to unreliable or even catastrophic designs

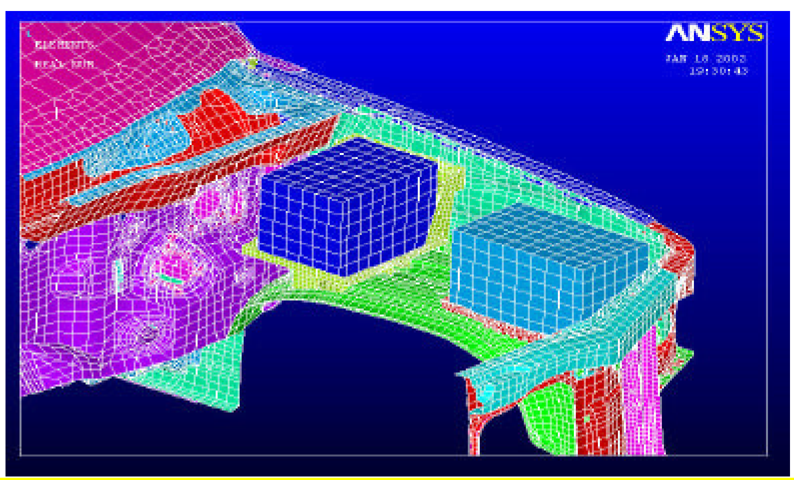
Workflow for Robust Design System

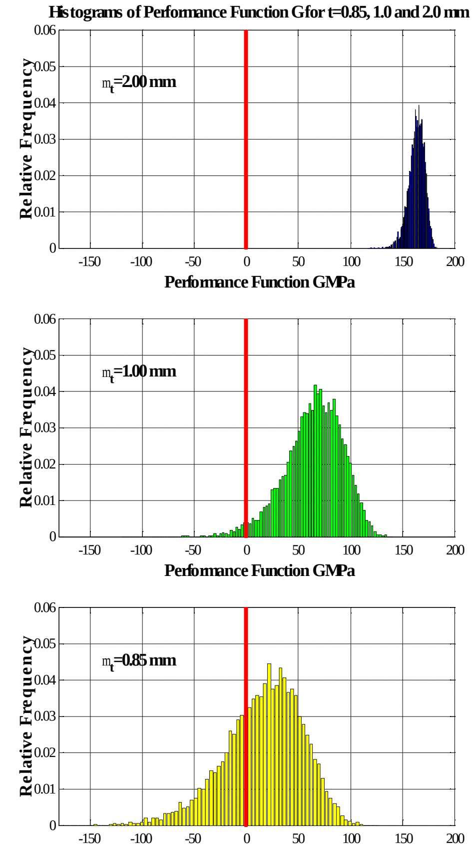


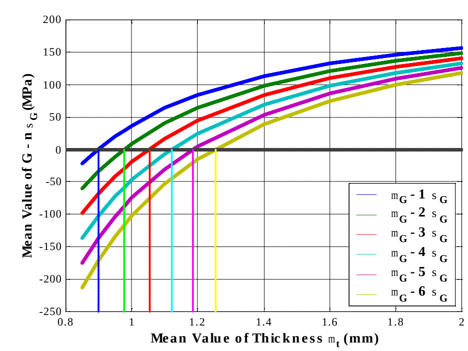




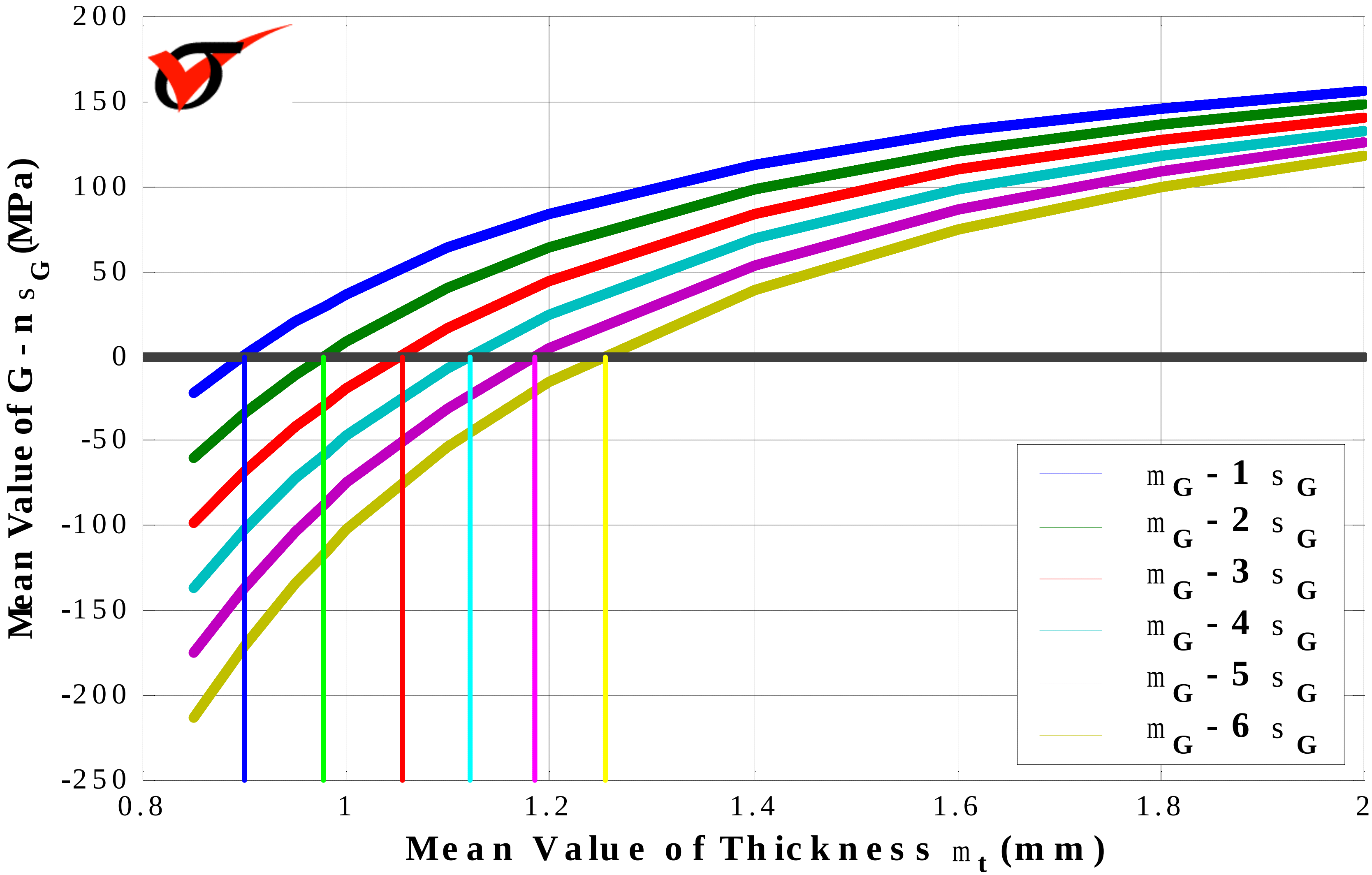




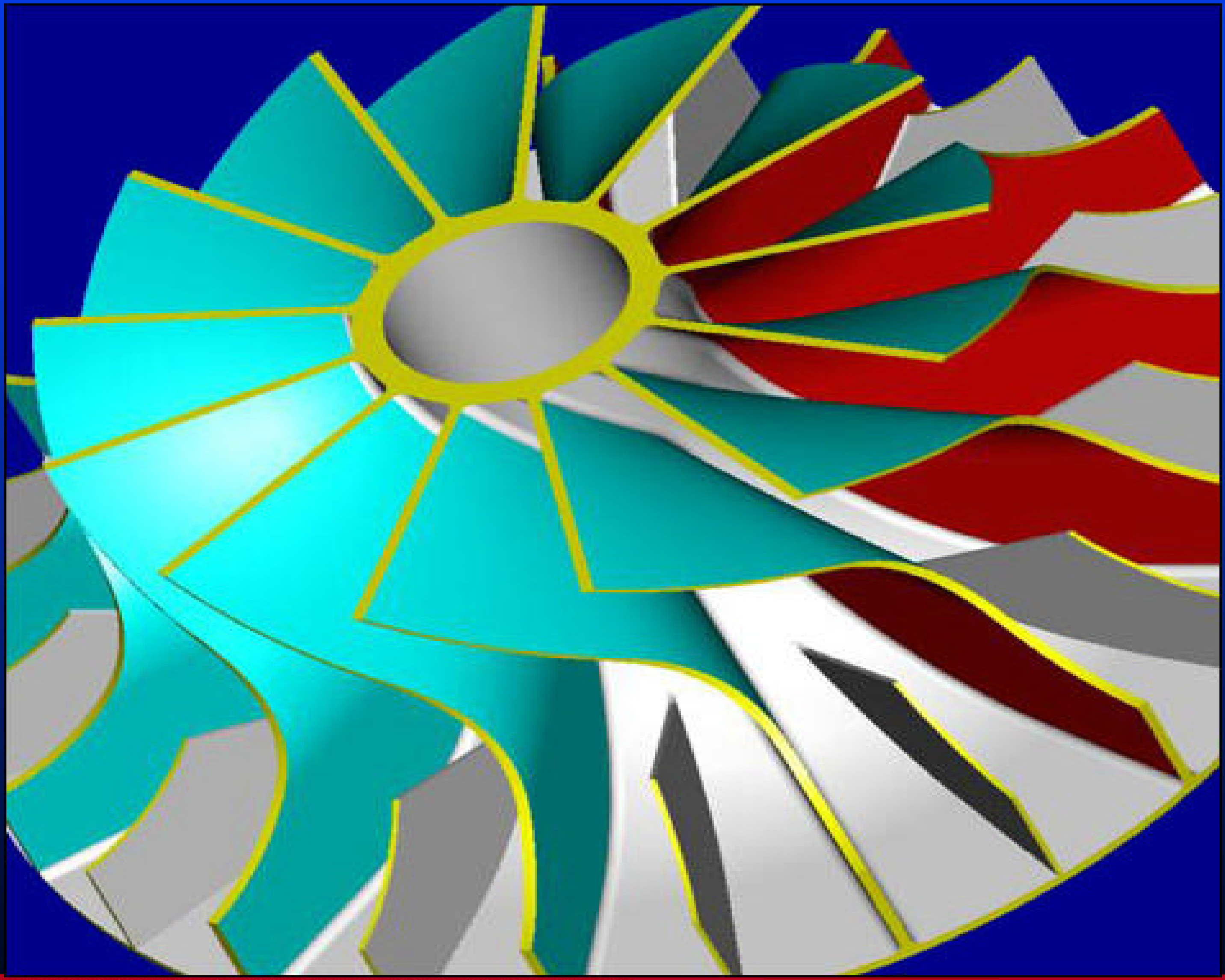




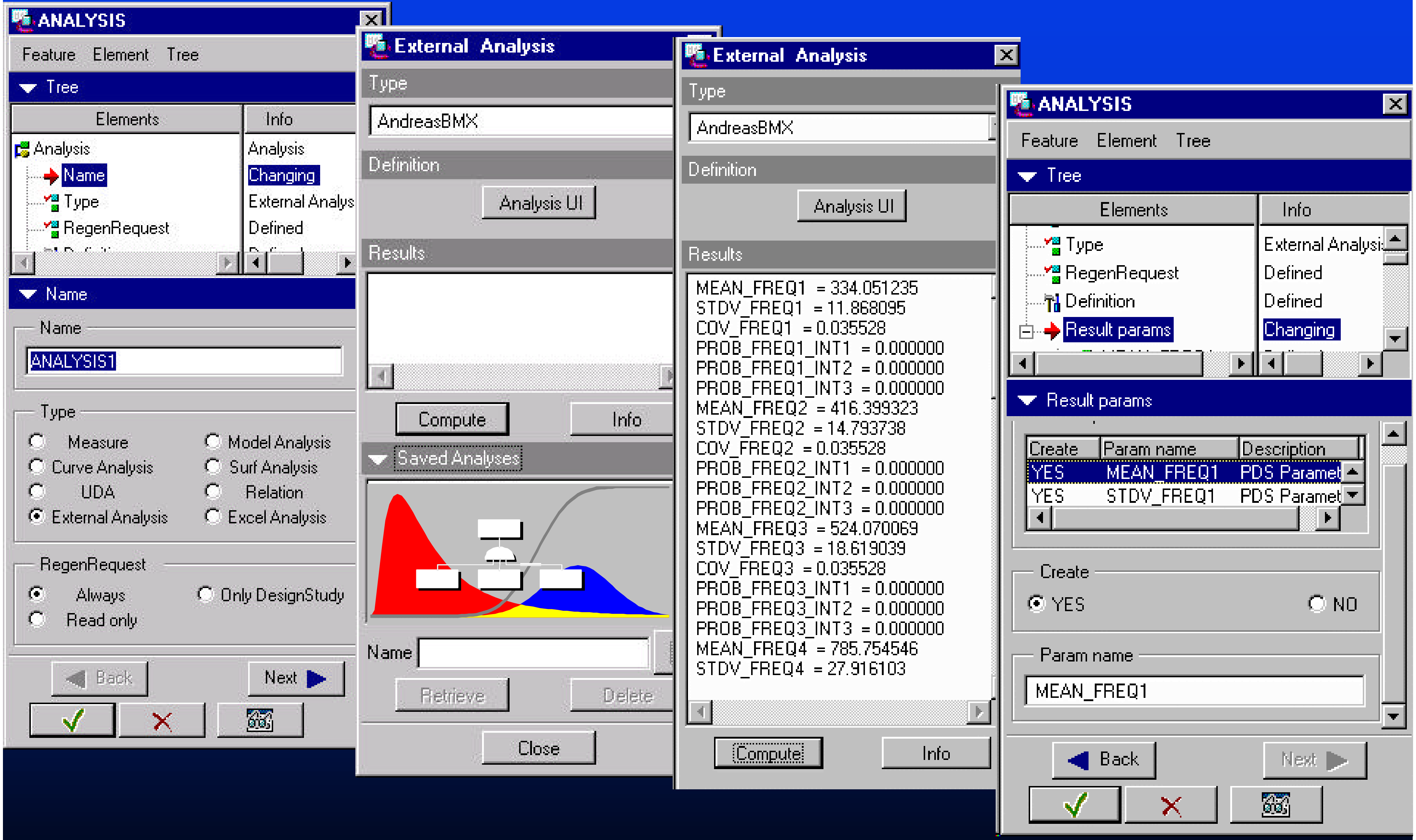
Performance Function **G** = $s_{ult} - s_{max}$



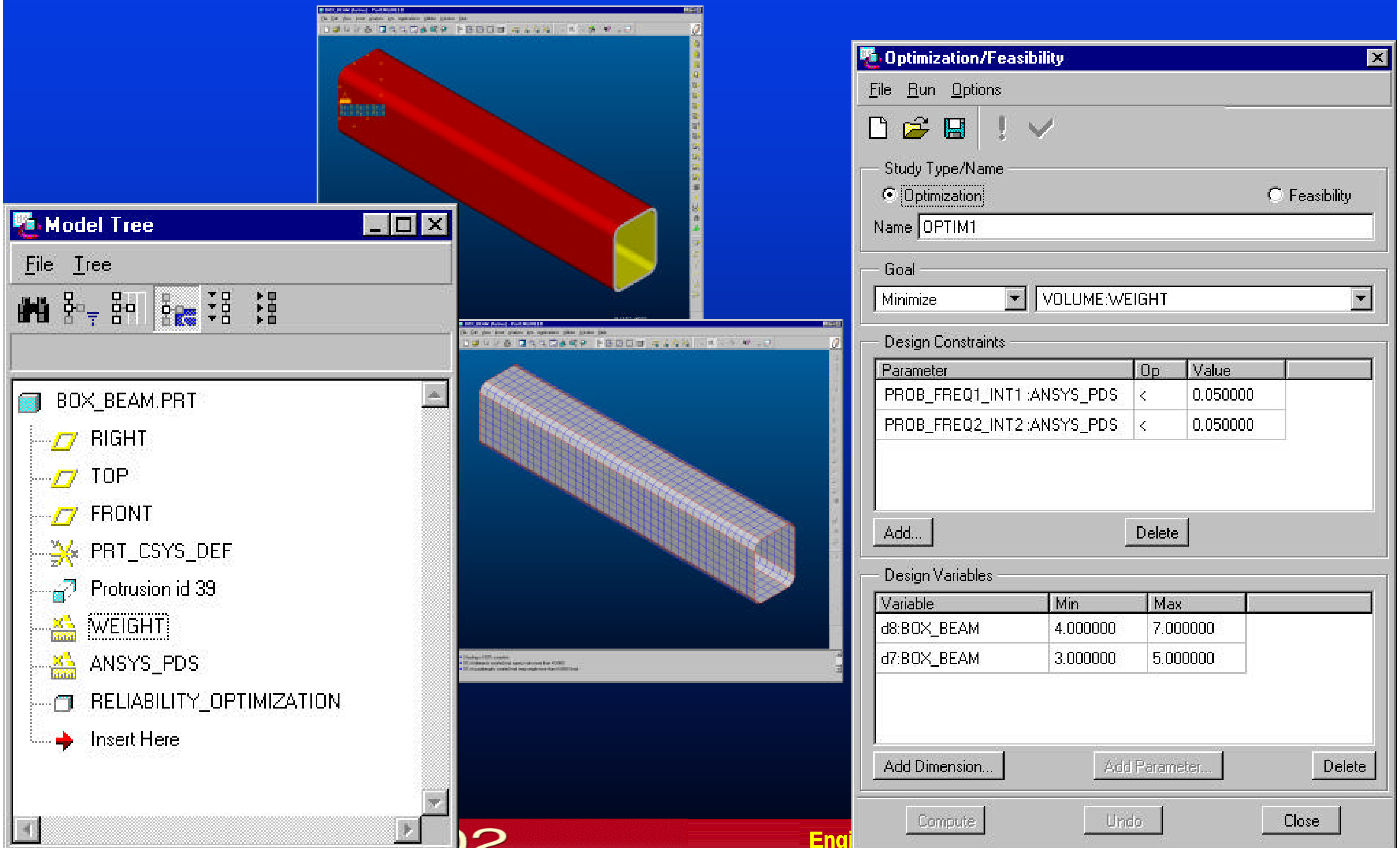
PDS for CAD Design Variables



Behavioral Modeling External Analysis – ANSYS_PDS



BMX External Analysis & Optimization Features



Pro-Engineer

Solid Model Feature 1

Solid Model Feature 2

Optimization Loop

Analysis Feature

Generate Parameters from Response Variables

Optimization Feature

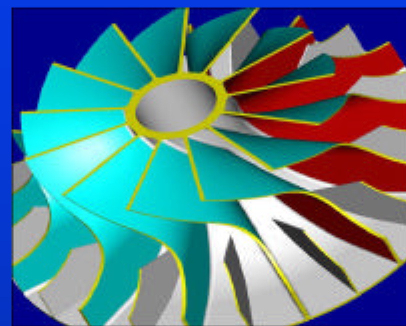
Establish Design Variables, Reliability Constraints and Perform Optimization to Compute Optimum Response Variables

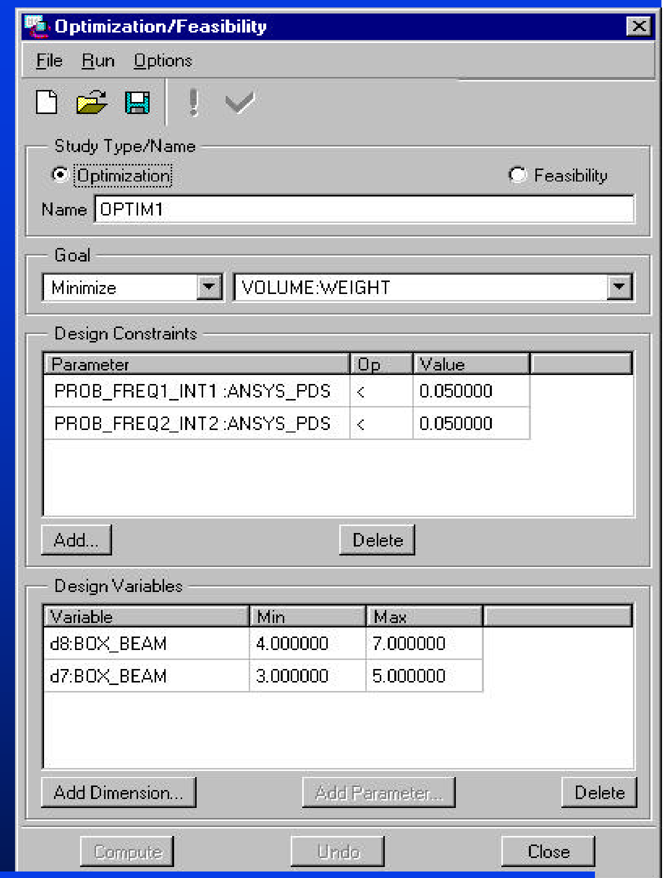
Create FE Mesh, Loads and BC

Create ANSYS input files

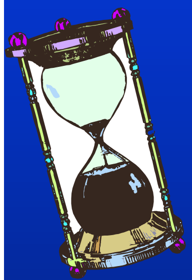
Compute Mean & Standard Deviation of Response Variables

Establish Random Variables and Perform Probabilistic Analysis





When a Designer makes a change (i.e. hole diameter) the component thickness updates automatically to meet desired quality criteria and **minimize weight** !



- Productivity improvements up to 90%
- Improve quality (6 σ) and system level performance (MDO)
- Enables integrated product development system
- Captures and utilizes design knowledge in early design stages
- Greater Utilization of Engineering Talent
    - Drudgery of multiple simulation runs passed onto computer
    - Greater portion of the engineer's time spent on fundamental engineering
    - More time to understand customer requirements and focus on design constraint definition


Create a Vision,
Adopt it,
Adapt to Achieve it